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Computer-Aided Neuro-fuzzy Algorithm for Prediction of Ginger(Zingiber officinale) Rhizome Drying

Oke Emmanuel Olusola[*1], Okereke Eze Aru[2], Igwe Johnson Eze[3], Nwankwo, Henry Frank[4]

[1,4]*Chemical Engineering Department, Michael Okpara University of Agriculture, Umudike, Nigeria*
[2]*Computer Engineering Department, Michael Okpara University of Agriculture, Umudike, Nigeria*
[3]*Mechanical Engineering Department, Michael Okpara University of Agriculture, Umudike, Nigeria*

*Corresponding author: oke.olusola@mouau.edu.ng (O.E. Olusola)

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ABSTRACT

Neuro-fuzzy modeling technique has been used for the development of computer-based adaptive process control systems for most postharvest operations instead of convectional mechanistic modeling technique owing to its good prediction without prior knowledge of process operation. Therefore, adaptive neuro-fuzzy inference system (ANFIS) modeling and prediction of ginger (Zingiber officinale) rhizome moisture content in a forced convective tray dryer was investigated in this study. Computer codes for an exhaustive search and grid partitioning were written in the Matlab software environment and used for the analysis of experimental data obtained from the ginger rhizome drying experiment. The data were trained and checked using the grid-partitioning ANFIS method for the development of neuro-fuzzy network for ginger drying prediction. The prediction accuracy of the network was evaluated by varying input and output Membership Function (MF) types. The exhaustive search analysis shows that drying time (DT) has the highest effect on the moisture content, followed by air drying temperature (ADT), air relative humidity (ARH), and air flow velocity (AFV). Moreover, combination of DT and ADT as two interactive variables; and combination DT, ADT and ARH as three interactive variables show highest effect on ginger moisture content removal during the process. Generalized bell (gbell) MF with two MF for each input variable and constant output MF type were obtained as the best ginger drying ANFIS network with corresponding R^2 and MSE of 0.9667 and 0.0971, respectively. Therefore, this study shows the reliability of the ANFIS model for the prediction of ginger rhizome drying in a tray dryer.

Keywords: Moisture Content; Modeling; Membership; Function; Prediction

1. Introduction

Ginger Rhizome, with the botanical name Zingiber officinale, is a tropical herbaceous plant belonging to the family Zingberaceae. It is native to southern China, Southeast Asia, and India. Ginger is currently extensively cultivated in tropical as well as subtropical regions of the world, especially in Asia and Africa. The total harvest area of ginger in the world is more than 21,000 ha, with a total production of more than 200,000 tons and an average yield of 10,000 kg per ha (Wang, 2020). Nigeria started the cultivation of ginger in 1927 in Southern Zaria, Jemma federated districts, and neighboring parts of Plateau State (Nair and Nair, 2019). Ginger is popular for its distinct sharp and hot flavor due to an oily substance called gingerol (Devi et al., 2017; Venu et al., 2017). It has been used, both in fresh and dry form, as a medicinal ingredient and spice in various countries around the world (Rajathi et al., 2017; Sachan et al., 2018). Ginger is mostly used in the form of curry powder, ginger bread, confectionary, table souse, ginger candy, ginger pickling, and in the manufacturing of certain soft drinks like cordials, ginger cocktails, carbonated drinks, ginger beer, and ginger wine (Ali and Rani, 2014; Ahammed et al., 2014; Kaushal et al., 2019). It also has antioxidant, antimicrobial, and anti-inflammatory properties (Nile and Park et al., 2015; Wang et al., 2018).

Due to the high demand for ginger rhizome in the world, there is a need for processing abundant and available ginger rhizome in most developing countries like Nigeria for both local consumption and international exportation. Thus, this requires cutting the rhizome into pieces that are well dried and properly stored. Drying is a traditional and easy technique for post-harvest preservation of food materials for subsequent use in the future. The drying process removes moisture from food material to a very low level, which consequently reduces deteriorative microbial activities over the product. It significantly reduces food product mass and volume, which enhances product transportation and storage. Plant materials are dried naturally; this involves exposing materials to atmospheric air or solar radiation. Natural drying is inexpensive; it may not need any equipment; consequently, it does not need technical manpower to drive the process. However, natural drying is slow, climatically dependent, and highly dependent on the method of stacking, which may lead to non-uniformity in the drying of product batches. Natural drying can only be considered for drying smaller quantities of materials; but with mass production of products for exportation, the use of mechanical drying becomes inevitable (Aviara et al., 2014).

Previous studies reported that air drying temperature, time, air flow velocity, air relative humidity, and geometry of the material influence the behaviour of the drying process (Sturm et al., 2014; Ju et al., 2016; Kouhila et al., 2020). Theoretical understanding of the ginger drying process is rarely documented in the literature due to the complex relationship that exists among the variables that influence the operation. The development of a process model that correlates the input and output variables of the process is the conventional alternative, which in turn can be used to control and optimize the process. Modeling processes broadens the understanding of experimental results and also creates knowledge about process behaviour. Furthermore, it can be used for the scaling up of pilot scale to industrial scale (Ojediran et al., 2020). Physics models that describe drying mechanisms such as thermodynamics, transport, physical properties, mass transfer for any given temperature, pressure, and condensed phase composition are cumbersome and difficult to solve or simulate. Oftentimes, the degree of model prediction and validity is decreased because of simplifying assumptions in the development of a practicable model (Si et al., 2019). However, black-box models are based on experimental results proposed to estimate the relationship that exists among process input-output variables. These models have the capability of modeling highly complex relationships with noisy input-output data. The models are also easier to develop and require less specialty than mathematical models (Oke et al., 2019; Zaidan et al., 2019).

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a black-box and soft-computing modeling technique that predicts different engineering problems, predominantly in chemical, food, mechanical, and biochemical processes. This method is a hybrid intelligent system that combines artificial neural networks (ANNs) and fuzzy logic. The ANFIS approach indicates an outstanding ability for learning and estimating uncertain systems and eventually provides a useful computing framework with reliable results (Abbas and Zhang, 2023). This technique is effective and efficient in predicting the complexity of nonlinear correlations between the input and output data using a hybrid learning method (Pourtousiet al., 2015). Compared with other mathematical and numerical techniques, this technique accurately predicted non-linear correlations (Ghoreishet al. 2015).

Previous studies show that ANFIS has found wide applications in the modeling of process parameters, especially drying processes (Abbaspour-Gilandeh et al., 2020; Pie et al., 2022). However, modeling and prediction of Nigerian ginger rhizome drying parameters and moisture content using ANFIS is scarcely found in the literature based on the author's knowledge. Therefore, this study is first aimed at analyzing the influence of drying time, temperature, relative humidity, and air flow velocity on the moisture content removal during forced convective ginger drying using an exhaustive search algorithm. Then, the obtained experimental data were used for developing an ANFIS architecture for ginger rhizome drying prediction.

2. Materials and Method

2.1 Sample Preparation

Fresh ginger rhizomes were procured from the National Research for Root Crops Institute, Umudike, Nigeria. The rhizomes were cleaned manually to remove all foreign matter such as dirt, pieces of stone, and broken rhizomes at the Food and Bio-process Engineering Laboratory, Agricultural Engineering Department, Michael Okpara University of Agriculture, Umudike, Nigeria.

2.2 Drying Experiment

Thermo Fisher Scientific HERATHERM OVEN (CP-21097) was employed for the experiment. The components of the schematic dryer diagram in Figure 1 are as follows: (1) Outdoor door (2) Door latch cut out (3) Door latch and handle (4) Door hinge lower (5) Leveling foot (6) Nameplate (7) Air battle top piece (8) Support rail for wire mesh shelf (9) Shelf support (10) Fan cover, integrated into air baffle (11) Door hook catch (12) Air baffle (13) Door seal (14) Stacking pad (15), spring for air baffle (16), temperature sensor (17), exhaust air tube.

The final moisture content of the dried sample was determined by the gravimetric method (AOAC, 1990) by direct heating in a drying oven at 105 °C for 48 hours.

$$MC = \frac{Wi - Wf}{Wf} X\ 100 \quad (1)$$

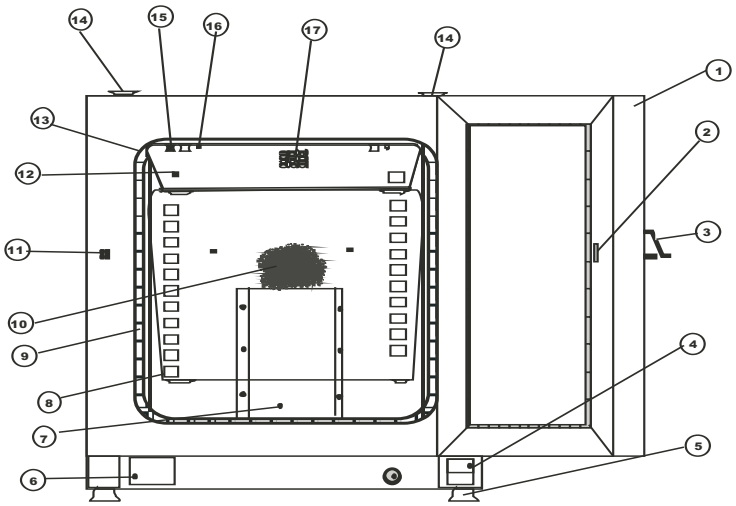

Figure 1: Schematic diagram of the dryer

Air at ambient conditions of 27–31 oC dry bulb temperature with an average of 26 oC and 63–78% relative humidity with an average of 71% was heated to the drying temperatures of 40, 50, 60, and 70 oC, respectively, using a tray dryer. This range of drying temperature was selected to prevent the active ingredients in the sample from deteriorating. For the experimental run at the above drying temperatures, the dryer fan was turned on and allowed to run for 2 minutes to enable it to stabilize at the specified air conditions before the test began.

The initial moisture content of the ginger was noted, and triplicate samples of ginger, each weighing 28 g and spread in a thin layer on a drying dish, were placed in drying trays and pushed into the drying chamber. The change in sample weight was monitored throughout the experiment by weighing the sample periodically using an electronic balance. Samples were weighed at 10-minute intervals in the first hour; thereafter, at 30-minute intervals until three consecutive readings gave identical weights. The test was then terminated, and the time taken was recorded. The percentage dry basis moisture contents of the samples were determined, and the average value was taken as the dynamic equilibrium moisture content (db). During the experiment, the ambient temperature, relative humidity, and inlet and outlet temperatures of the drying air were recorded using a temperature meter, a hydrometer (CD-6 CSX 500-196-20), and an anemometer (CR 2032), respectively.

2.3 One-Factor at a Time (OFAT) Drying Kinetic Experiment

In this study, the OFAT kinetic experiment was designed at different ambient temperatures and relative humidity values with constant drying temperatures of 40 °C to 70 °C. The design of the experiments is shown in Tables 1–4.

2.4 ANFIS Model Development.

Artificial neural networks (ANN) and fuzzy inference systems (FIS) are combined, resulting in an adaptive neuro-fuzzy inference system (ANFIS) for solving and explaining imprecise as well as uncertain problems. In this work, the Takagi-Sugeno fuzzy system was applied to the fuzzy inference system to model the complex system. X and Y are the input variables, and one output (Z) variable was used to symbolize the ANFIS architecture as illustrated in Figure 2. The ANFIS architecture comprises five layers, as shown in Figure 2. Square nodes (adaptive nodes), in Figure 2, show that the parameters in these nodes are modifiable; to be learned, while the circle nodes (fixed nodes) show that they are fixed parameters. A common rule set with two fuzzy if-then rules is as follows:

Rule 1: If x is A_1 and y is B_1, then $f_1 = p_1 x + q_1 x + r_1$ (2)

Rule 2: If x is A_2 and y is B_2, then $f_2 = p_2 x + q_2 x + r_2$ (3)

Where A and B are linguistic terms that are user-defined and represent a range of values. The sequence and functions of the layers are as follows:

Layer 1: Square node equipped with node function

$$O_i^L = \mu_{Ai}(x) \quad (4)$$

Assuming x and y are the two typical input values fed at the two input nodes, which then transforms those values into the input membership functions. Where is the membership function of and x is the input parameter to the node. is the linguistic label connected with the node function.

Layer 2: This node increases the homeward bound signal and releases the product out of the layer

$$w_i = \mu_{Ai}(x)\ X\ \mu_{Ai}(y),\ i = 1,2 \quad (5)$$

Layer 3: circle node. Node calculates the ratio of the i-th rule's firing strength to the sum of all rules' firing strengths:

$$w_i' = \frac{w_i}{w_1 + w_2},\ i = 1,2 \quad (6)$$

Layer 4: Square node with node function:

$$O_i^4 = w_i f_i = w_i'(p_i x + q_i y + r_i) \quad (7)$$

Layer 5: circle node. This node computes the overall output as a sum of all incoming signals.

$$O_i^5 = \text{overall output} = \Sigma_i \; w_i^1 f_i = \frac{\Sigma_i w_i f_i}{\Sigma_i w_i} \quad (8)$$

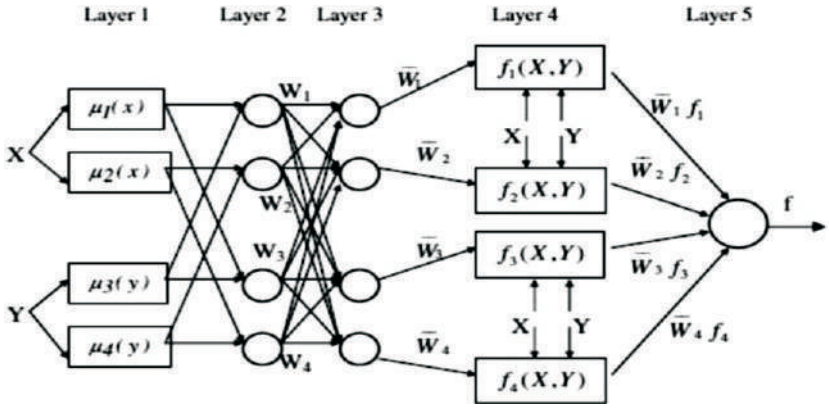

Figure 2: A basic structure of the ANFIS

2.5 Performance Evaluation of ANFIS Models

Statistical parameters were applied in order to evaluate the performance of the proposed model for the prediction of the ginger moisture content. RMSE (root mean square error) and the R2 value (correlation coefficient) were used as shown in Equations 9 and 10.

$$R^2 = 1 - \frac{\Sigma_{p=1}^{p}(d_p - O_p)^2}{\Sigma_{p=1}^{p}(- O_p)^2} \quad (9)$$

$$\text{RMSE} = \sqrt{\frac{1}{p}\Sigma_{p=1}^{p}(d_p - O_p)^2} \quad (10)$$

Where dp and Op are the desired and calculated outputs, respectively. The RMSE value close to zero and the R2 value close to one show the good predictability and reliability of the models (Oke et. al. 2014).

3. Results and Discussion

3.1 Drying curves of ginger Rhizome in a tray dryer

Table 1 presents the kinetic experimental design matrix of ginger rhizome drying in a convective tray dryer. Figure 3 shows the variation of the ginger moisture content with time during the drying at different temperatures in the range of 40–70 oC. From the Figure 3, it shows that the moisture content decreased with an increase in time until the dynamic equilibrium moisture content at each of the drying temperatures was attained. The trend of this result is similar to previous investigations (Aviara et al., 2014; Rathore et al., 2020). It was also observed in the moisture content-time curves in Figure 3 that as the drying temperature increased, the rate of moisture transfer from the sliced ginger increased. Although the rate of moisture content transfer during convective ginger drying using 40 and 50 oC is close to each other. Figure 3 revealed that the highest moisture transfer rate and effective sliced ginger rhizome are achieved at 70 oC.

Table 1: Ginger drying kinetic experimental design matrix of independent and dependent variables

Drying time (mins)	40 °C			50 °C			60 °C			70 °C		
	A	B	MC (db)	A	B	MC (db)	A	B	MC (db)	A	B	MC (db)
0	78	3.2	1650	76	5.0	1650	73	4.2	1650	75	3.4	1650
10	75	4.0	1583.54	75	4.0	1539.024	72	6.1	1528.05	73	3.0	1179.27
20	75	4.0	1512.81	66	4.1	1434.756	71	7.9	1392.07	73	4.0	1006.71
30	68	4.3	1451.83	64	4.0	1345.732	70	4.0	1261.59	72	4.0	852.43
40	73	4.0	1329.27	66	4.0	1253.659	66	5.9	1140.85	72	4.0	707.32
50	73	4.0	1265.85	68	6.0	1159.756	65	4.3	1024.39	72	4.5	585.98
60	73	4.1	1085.37	68	5.7	1070.732	64	5.4	916.46	72	4.5	461.59
90	75	4.0	921.34	76	4.0	803.0488	63	5.3	630.49	73	4.3	223.17
120	75	5.3	767.07	76	5.4	608.5366	73	4.0	416.46	73	4.6	103.66
150	74	4.5	632.32	77	4.0	462.1951	71	4.6	281.09	72	3.8	64.02
180	74	4.2	523.78	71	4.5	358.5366	72	5.0	206.09	68	4.1	53.66
210	73	4.0	353.05	76	4.7	292.0732	72	5.0	174.39	68	4.2	51.83
270	74	4.1	258.54	75	5.9	235.3659	72	6.2	153.66	68	4.2	48.78
330	75	5.3	200	75	6.3	221.9512	70	4.7	148.78	68	4.2	48.78
390	74	6.1	176.83	76	6.1	215.8537	70	4.0	145.12	68	4.2	48.78
450	72	5.9	167.07	78	2.5	212.8049	70	4.0	145.12			
510	78	4.0	160.37	78	6.4	210.3659	70	4.0	145.12			
570	76	4.1	156.71	78	6.2	210.3659						
630	75	4.0	153.05	77	6.0	210.3659						
690	73	4.1	151.22									
750	73	4.1	151.22									
810	73	4.1	151.21									

MC: moisture content; db: dry basis; A: relative humidity (%); B: air velocity (m/s)

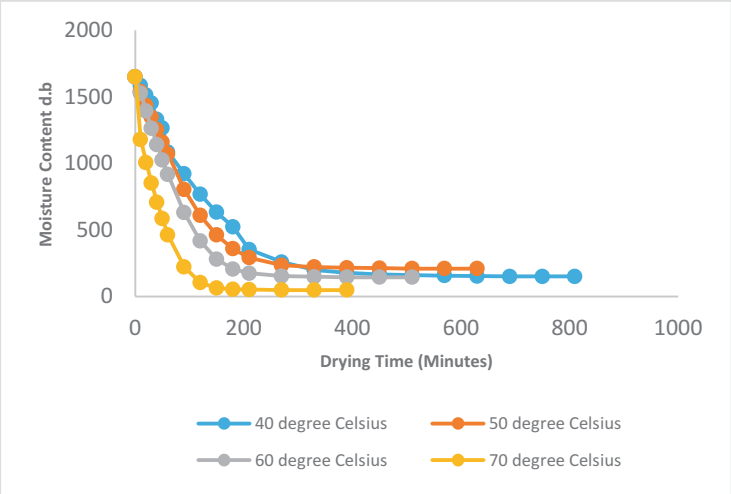

Figure 3: Drying curve of ginger slice at different temperatures in a tray dryer

3.2 Drying Input Exhaustive Search Result

An exhaustive search model was used to understand the effect of one-two-three input variables on ginger moisture content in a convective tray dryer. Tables 2, 3, and 4 present the results of an exhaustive search model for one, two, and three variables, respectively. Table 2 reveals an exhaustive ANFIS model result with a single input variable, and it was observed that drying time has the least RMSE. This indicated that this input variable (drying time) is the most influential variable that affects moisture content removal during ginger drying. Table 3 shows the result of two input combinations using an exhaustive search model. It was noticed from Table 3 that drying time and temperature show the least RMSE and this suggests that interaction of drying time and temperature have the most significant effect on the process. Table 4 presents the effect of a combination of three input variables on the moisture content of ginger during forced convective tray drying. The three input variables analyzed in Table 4 indicated that the combination of drying time, temperature, and air relative humidity was the best combination with the least RMSE. However, the combination of drying time, air relative humidity, and air flow velocity has the least effect on the process, as suggested by the RMSE value in Table 4. These combinations are consistent with previous research (Kisi et al., 2009; Aviara et al., 2014).

Table 2: Exhaustive search result of one-input variable

No of Input	Input Variable	Training RMSE	Checking RMSE
1	Temperature	4.046	4.10
1	Time	1.637	1.685
1	Relative humidity	4.089	4.097
1	Air velocity	4.60	4.21

Table 3: Exhaustive search result of two -input variable

No of Input	Input Variable	Training RMSE	Checking RMSE
2	Time, Temperature	0.935	1.228
2	Temp., Relative humidity	3.42	3.809
2	Temp., Air Velocity	3.096	6.82
2	Time, R. Humidity	1.372	1.638
2	Time, Air velocity	1.512	2.074
2	R. Humidity, Air velocity	3.086	7.28

Table 4: Exhaustive search result of three-input variable

No of Input	Input Variable	Training RMSE	Checking RMSE
3	Time, R. Humidity Temp.	0.49	2.261
3	Temp., Time, R. humidity	0.574	11.34
3	Temp, R. humidity, Air Vel.	1.96	15.93
3	Time, R. Humidity, Air Vel	9.445	23.24

3.3 ANFIS model validation

The best type of input and output Membership Function (MF) as well as the number of input MF for the prediction of ginger moisture content were evaluated by using different input MFs such as gbell, trap, gauss, gauss2, dsig, pi, and tri with a high epoch number of 200. Table 4 shows the preliminary results of the ANFIS structure simulation at different input MFs with constant type as the output MF type and two as the number of input MFs. Different correlation coefficient values were obtained (0.599–0.9669), as indicated in Table 4. It was observed that Gbell MF possessed the highest R2 value; however, using the linear type output membership function, the range of R2 values lies between 0.2538 and 0.711, as also indicated in Table 4. From table 5, it was also observed that ANFIS settings with input gbell MF and constant type MF could predict ginger moisture content in a tray dryer. Further investigation was conducted by using three input MFs and constants as well as a linear output MF type, as shown in Table 6. It was observed that the computational time for building this ANFIS architecture was more than the computational time required for the two input MF.

Table 5: Preliminary simulation for optimum parameters for ANFIS model

Input MF type	Number of Input MF type	Output MF	R^2
gbell	2	constant	0.9667
tri	2	constant	0.7891
gauss	2	constant	0.7185
gauss2	2	constant	0.710
trap	2	constant	0.7008
pi	2	constant	0.7109
dsig	2	constant	0.5990
gbell	2	linear	0.7112
tri	2	linear	0.6180
gauss	2	linear	0.6420
gauss2	2	linear	0.3430
trap	2	linear	0.5469
pi	2	linear	0.2538
dsig	2	linear	0.0310

Table 5: Further Simulation for optimum parameters for ANFIS model

Input MF type	Number of Input MF type	Output MF	R^2
gbell	3	linear	0.5428
tri	3	constant	0.6167
gbell	3	linear	0.7185
tri	3	linear	0.6634

In addition, Figure 4 compares ANFIS predicted data with the experimental results of moisture content during ginger convective drying. It was observed that both the experimental and predicted results are comparable. Figure 4 shows that R2 and adjusted R2 gave 0.9667 and 0.9337, respectively. Based on the coefficient of determination (R2 = 0.9669) and adjusted R2 value, it is evident that the prediction agreed quite well with the experimental data. The coefficient of determination was close to 1, and the RMSE of the comparison value was near zero, which is an indication that the degree of predictability of the model is adequate and reliable (Ghoreish et al., 2015). Figure 5 shows the ANFIS model structure with two input gbell MFs and a constant output MF. The structure in Figure 5 reveals that the network contains sixteen (16) fuzzy rules and forty (40) parameters, which consist of sixteen (16) and twenty-four (24) linear and non-linear parameters, respectively.

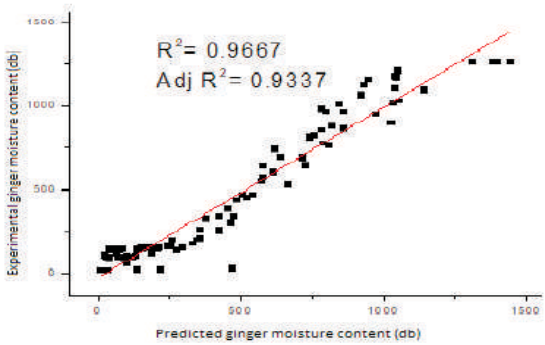

Figure 4: Comparison of ANFIS predicted and experimental moisture content

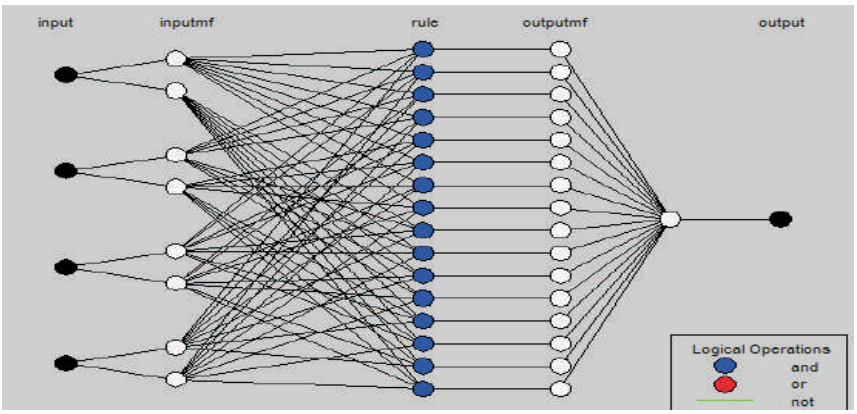

Figure 5: ANFIS model structure with two input gbell MF and constant output MF

4. Conclusion

In this work, ginger moisture content during forced convective drying in a tray dryer was predicted by using the grid-partitioning ANFIS method. To assess the efficiency of the model, the RMSE value is 0.0905 and the R2 value is 0.9667. The ANFIS simulation results are given in the related tables. The simulation results have shown that the ANFIS can be used as an alternative prediction method for modeling the moisture content of the drying process.

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